HYD 268

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OPERATION AND CALIBRATION TESTS OF A 12-INCH INTERNAL DIFFERENTIAL NEEDLE VALVE FOR GRANBY DAM AUXILIARY OUTLET--COLORADO-BIG THOMPSON PROJECT, COLORADO

Hydraulic Laboratory Report No. Hyd.-268

RESEARCH AND GEOLOGY DIVISION

BRANCH OF DESIGN AND CONSTRUCTION
DENVER, COLORADO

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Branch of Design and Construction
Research and Geology Division
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Laboratory Report No. Hyd 268
Hydraulic Laboratory
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Subject: Operation and calibration tests of a 12-inch internal differential needle valve for Granby Dam Auxiliary Outlet—Colorado-Big Thompson Project, Colorado

PURPOSE

Hydraulic studies were made on a 12-inch internal differential needle valve to determine its discharge characteristics and to ascertain whether its hydraulic actuating mechanism would perform satisfactorily. The valve will be used to regulate releases from an auxiliary outlet at Granby Dam.

CONCLUSIONS

1. The modified hydraulic actuating mechanism (Figure 1) will operate satisfactorily provided sufficient pressure head is supplied to the mechanism. The required minimum pressure head "H," in feet of water, is given by the equation:

$$H = 0.0468\ Q^2 + 3.09$$

where "Q" is the valve discharge in cubic feet per second (Figure 3).

2. When the source of the actuating pressure is from the outlet conduit, the minimum total head at which the actuating mechanism will function properly depends upon the pressure head in the conduit, which in turn depends upon the conduit size. The following table shows the minimum total head at which the hydraulic mechanism will function properly for various sizes of conduit leading to the valve. The table reflects the condition for the fully open valve.

Source of the actuating supply	Minimum operable total head
Reservoir	11 feet
18-inch conduit	20 feet
16-inch conduit	34 feet
14-inch conduit	62 feet
12-inch conduit	Will not operate because of insufficient pressure head

3. When there is sufficient actuating pressure head supplied to the mechanism, the needle will move smoothly in either direction, requiring slight torque on the operating handwheel. As the needle nears the closed position, the handwheel must be turned slowly to prevent the valve "slamming" shut, resulting in severe water hammer.

4. When the valve opening is being changed and the operating handwheel is stopped, the needle will continue to move about one-fourth inch before the actuating valve is positioned to equalize the pressure on the diaphragm and prevent further movement of the needle.

5. For various total heads in the actuating supply line the leakage through the mechanism will be as shown by the curve on Figure 5.

6. The jet produced by the valve is smooth and steady for all openings larger than about 10 percent; at smaller openings, the jet tends to ravel and spread out causing considerable spray.

7. The discharge coefficient "C_d" in the equation, $Q = C_d A\sqrt{2gh}$ is 0.62 for the fully open valve. A chart has been prepared from which the discharge coefficient and the discharge for any percentage of valve opening may be obtained (Figure 7).

INTRODUCTION

A study of the requirements for an auxiliary outlet control valve at Granby Dam indicated that a 12-inch internal differential needle valve in storage at Hoover Dam could be utilized provided certain minor alterations were made. The valve was 1 of those intended to control the flow through the 12-inch bypasses around the 168-inch butterfly valves in the power penstocks at Hoover Dam. These valves had been removed when they failed to operate satisfactorily and the source of the trouble was not apparent.

A study of the details and history of the needle valves by members of the Mechanical Division disclosed that the operating difficulties might have resulted from the arrangement of water passages in the actuating mechanism and leakage between pressure chambers within the valve. They recommended that one of the valves be altered and placed in the Hydraulic Laboratory for tests to determine if satisfactory operation could

be obtained. The work was authorized and 1 of the valves modified as recommended (Figure 1). Tests were made to study the effect of the modifications and to obtain data from which discharge capacity and other valve characteristics could be determined.

THE STUDY

Laboratory Installation

The modified 12-inch needle valve was installed to operate under free discharge. A 20-foot length of 12-inch pipe was placed upstream to assure uniform flow at the valve. It was installed so that water could be supplied by any or all of the laboratory pumps, and the discharge could be measured by a venturi meter. The head to actuate the valve needle was originally supplied through a 1-inch pipe tapped into the 12-inch line 1 foot upstream from the valve; later, when the head at this point proved too small to operate the valve hydraulically, an auxiliary supply line was connected through a pressure regulating valve to the city water main.

Two piezometers, 1 in the 1-inch actuating supply line near the entrance port, and the other in the 12-inch conduit 1 diameter upstream from the valve, were used to measure the respective pressure heads. A point gage, utilizing a thin blade for measurements through the jet, was mounted on the downstream face of the valve (Figure 2) and calibrated against the movement of the needle so that the amount of valve opening could be measured at any time without interrupting the flow through the valve.

Valve Operation

When the actuating supply was drawn from the 12-inch conduit, and the full capacity of the laboratory pumps (about 20 cubic feet per second) passed through the valve, the hydraulic actuating mechanism operated satisfactorily only for valve openings below 80 percent. For total heads on the valve of less than 4 feet, the actuating mechanism would not move the needle from any position. The valve could be opened and closed manually however, by applying a large torque to the operating handwheel.

With the actuating supply taken from the city water main, tests were continued to find the minimum pressure head necessary to start the valve closing from the 100-percent open position since a pressure head sufficiently large to start the valve closing from this position would be satisfactory for the full range of valve openings. Computations and charts pertaining to the operating mechanism reflect the conditions with the valve fully opened.

Determination of the Minimum Actuating Head

The test procedure to determine the minimum actuating pressure head necessary to start closing of the valve consisted of:

1. Regulating and recording the discharge through the wide-open valve
2. Decreasing the actuating pressure head until it was too small to move the needle hydraulically
3. Turning the actuating handwheel toward "close"
4. Increasing the actuating pressure head until the needle just started to move
5. Recording the actuating pressure head in the 1-inch line

The minimum pressure head in the actuating supply line to operate the valve hydraulically was determined by the above procedure for each of several discharges up to 15.6 cubic feet per second.

If the valve is to operate hydraulically, the force against the needle in the pressure chamber (Figure 3) must be great enough to overcome both the force "F" on the needle due to the valve discharge and the friction between the needle and the tube. The pressure at any point on the exposed surface of the needle which produces the force "F" varies as the square of the velocity past that point, and the velocity varies directly as the discharge; therefore, the total force against the nose of the needle varies as the square of the discharge through the valve.

The force against the needle in the pressure chamber varies directly as the actuating pressure head; therefore, the actuating pressure head necessary to close the valve against the force caused by the valve discharge must vary as the square of this discharge. The friction between the moving needle and its housing must be overcome by an additional head.

It follows that the terms of an equation of the form:

$$H = B\,Q^2 + D$$

which could enable determination of the required actuating pressure head, could be evaluated from the experimental data where:

H = Pressure head, feet of water, in the actuating supply line
B = A constant
Q = Valve discharge, cubic feet per second
D = Pressure head, feet of water, necessary to overcome the friction of the valve

Using the experimental data, a chart was made plotting the actuating pressure head versus the square of the valve discharge (Figure 3). The slope of the resultant line is the constant "B" and the intercept of the plotted line with the zero discharge ordinate is the value "D." Substituting these constants into the equation, the minimum actuating pressure head (H) to operate the valve hydraulically from the fully open position for any discharge (Q) is:

$$H = 0.0468\,Q^2 + 3.09$$

Figure 4 shows the relation between the valve discharge (Q) and:

1. The total head immediately upstream from the valve
2. The minimum actuating pressure head to operate the valve hydraulically (determined by using the above equation)
3. The pressure head for a 12-inch, 14-inch, and 18-inch diameter conduit section upstream from the valve

Actuating Mechanism Leakage

Leakage through the actuating mechanism was measured volumetrically for pressure heads in the 1-inch line from 1.5 to 29.0 feet. Tests were made with the valve fully open, with and without flow through the valve; and the valve closed, with and without pressure on the upstream side of the valve. Assuming that the leakage through the actuating mechanism varied as the square root of the total head, a value "K" was determined for each test run where $K = \frac{\text{leakage}}{\sqrt{h}}$. A plot of these values indicated that "K" became constant (about 0.0052) for total heads above 18 feet. Using this value of "K," a plot of leakage against total head was made for the actuating supply leakage up to a head of 185 feet (Figure 5). It was found that, for the same actuating pressure head, the actuating supply leakage was somewhat smaller when the needle was in the closed position than when it was wide open, and that the amount of head or flow in the conduit made little difference in this leakage.

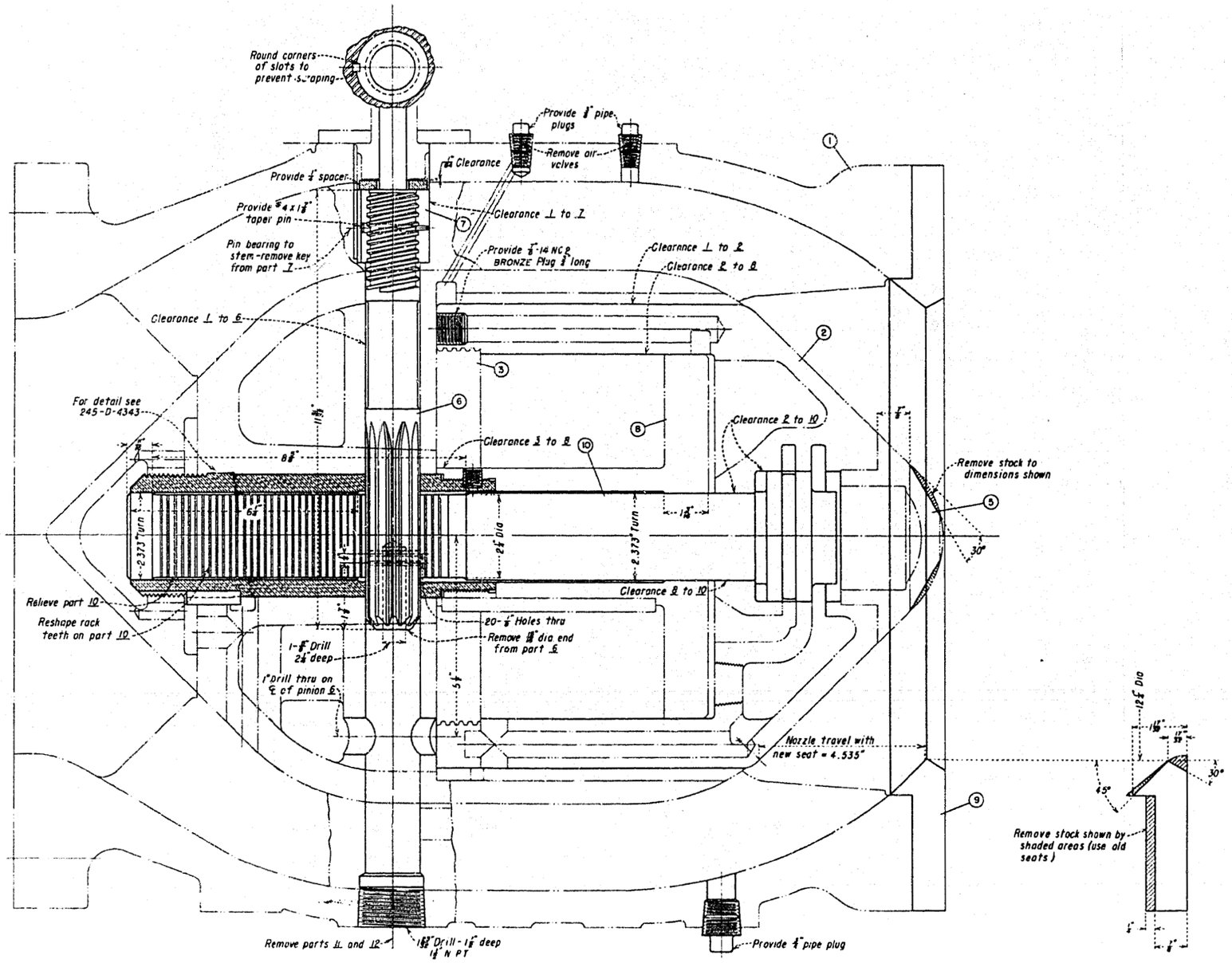
Valve Capacity

Data necessary to compute the discharge coefficients of the valve consisted of the pressure head at the valve, the discharge, and the amount of valve opening. These data were obtained for 5 valve openings and for discharges which ranged from the smallest at which the valve would flow full to the maximum output of the laboratory pumps. Discharge coefficients for the valve were computed for various valve openings by using the formula, $Q = C_d A \sqrt{2gh}$, where:

Q = Discharge, cubic feet per second
C_d = Discharge coefficient
A = Area of the 12-inch pipe, square feet
h = Total head at the valve, feet of water, (pressure head + velocity head)

Within the range of the laboratory pumps the coefficients were nearly constant for any 1 valve opening (Figure 6). Since C_d was constant for all practical purposes, a curve of C_d versus valve opening was plotted which was used in preparing a discharge chart covering the entire range of reservoir elevations at Granby Dam (Figure 7).

Tests were not made concerning pressures within the discharge passages of the valve; however, the valve's blunt downstream needle tip might be damaged by cavitation if the valve releases water for long periods at partial openings and under high heads.



SCHEDULE OF WORK TO BE DONE

1. Clearance part 1 to 2 should be .008" to .012"
2. Clearance part 2 to 8 should be .004" to .006"
3. Clearance part 3 to 8 should be .003" to .008"
4. Clearance part 8 to 10 should be .002" to .004"
5. Clearance part 2 to 10 at 3⅞ dia. should be .001" to .003"
6. Clearance part 8 to 10 at 2⅜" dia. should be .002" to .004"
7. Clearance part 1 to 6 should be .004" to .007"
8. Clearance part 1 to 7 should be .003" to .006"
9. Relieve part 8 - 1/16 on 2⅜" dia., ream as shown.
10. Relieve part 10 - 1/32 on 2⅜" dia., turn as shown
11. Remove 1⅛" dia. end from part 6 and drill ¾" hole 2¼" deep and drill 2-¾" holes thru each space between pinion teeth.
12. Remove key from parts 1 and 7 and taper pin, part 1 to 7.
13. Provide brass spacer 1⅜" O.D. x ⅝" I.D. x ¼" thick.
14. Remove parts 11 and 12, and drill and tap for 1¼" pipe in place of 1⅛" dia. tap for 11.
15. Plug upper ⅝" hole in part 2 in same manner as shown for bottom ⅝" hole.
16. Drill 1" hole thru part 1, as shown, to open upstream chamber to 1¼" drain.
17. Reshape rack teeth by hand filing in part 10 to avoid tooth interference with pinion 6.
18. Alter part 9 as shown.
19. Manufacture part 8, as shown on 245-D-4343.
20. Modify part 5, as shown.
21. Remove air valves and provide 2-¾" pipe plugs.
22. Provide ¾" pipe plug.

REFERENCE DRAWINGS

12" INTERNAL DIFFERENTIAL NEEDLE VALVE - ASSEMBLY 45-D-2686
12" NEEDLE VALVE - DETAILS 245-D-4343

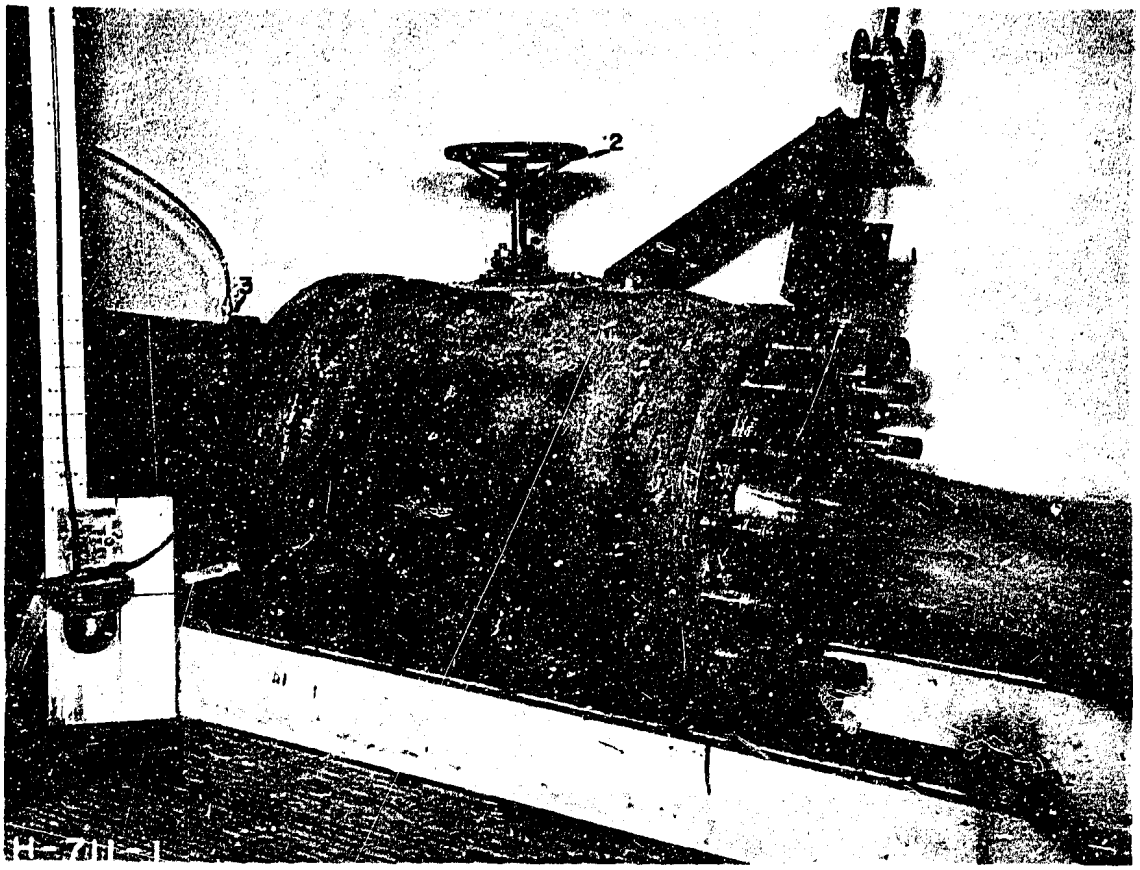
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO BIG THOMPSON PROJECT - COLO.

GRANBY DAM
OUTLET WORKS
12" NEEDLE VALVE REPAIR

DRAWN	H.P.O.	SUBMITTED	W. G. Weber
TRACED	E.O.L. - E.M.W.	RECOMMENDED	H. E. Sheda
CHECKED	J.W.A.	H&W APPROVED	L. N. McClellon, ASST. CHIEF ENGINEER

DENVER, COLORADO SEPT. 17, 1947
SHEET 1 OF 2

245-D-4342



12-Inch Internal Differential Needle Valve Operating Partially Opened Under a Head of About 60 Feet.

Key to numbers:

1. Gage for determining the position of the needle without interrupting the flow.
2. Operating hand wheel.
3. Piezometer opening in 12-inch pipe.

COLORADO-BIG THOMPSON PROJECT--COLORADO
GRANBY DAM OUTLET WORKS
12-INCH NEEDLE VALVE

FIGURE - 3

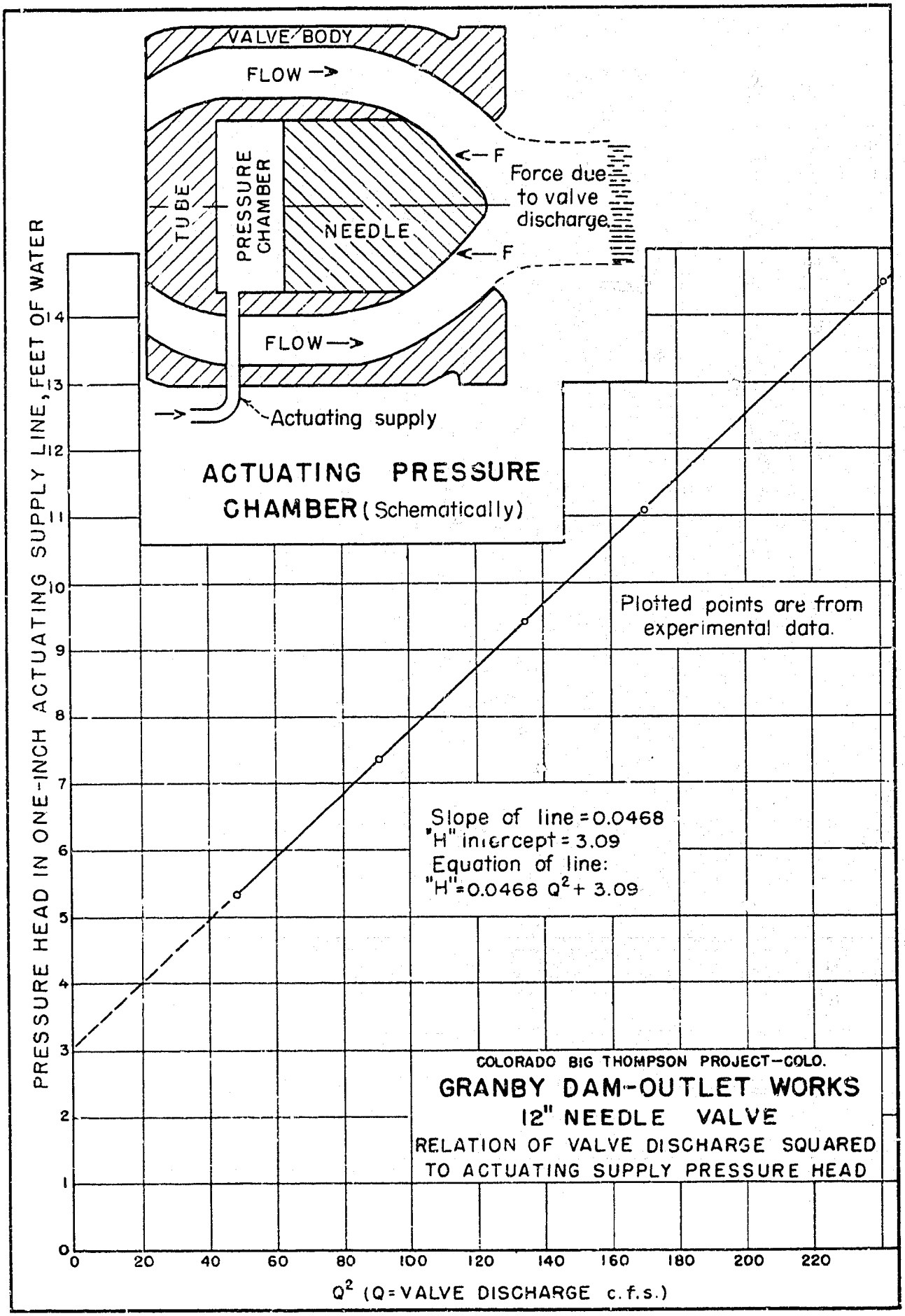

VALVE BODY
FLOW →
F
Force due to valve discharge
TUBE
PRESSURE CHAMBER
NEEDLE
F
FLOW →
Actuating supply
ACTUATING PRESSURE CHAMBER (Schematically)
Plotted points are from experimental data.
Slope of line = 0.0468
"H" intercept = 3.09
Equation of line:
"H" = 0.0468 Q² + 3.09
PRESSURE HEAD IN ONE-INCH ACTUATING SUPPLY LINE, FEET OF WATER
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
0
20
40
60
80
100
120
140
160
180
200
220
Q² (Q = VALVE DISCHARGE c.f.s.)
COLORADO BIG THOMPSON PROJECT—COLO.
GRANBY DAM-OUTLET WORKS
12" NEEDLE VALVE
RELATION OF VALVE DISCHARGE SQUARED TO ACTUATING SUPPLY PRESSURE HEAD

FIGURE 4

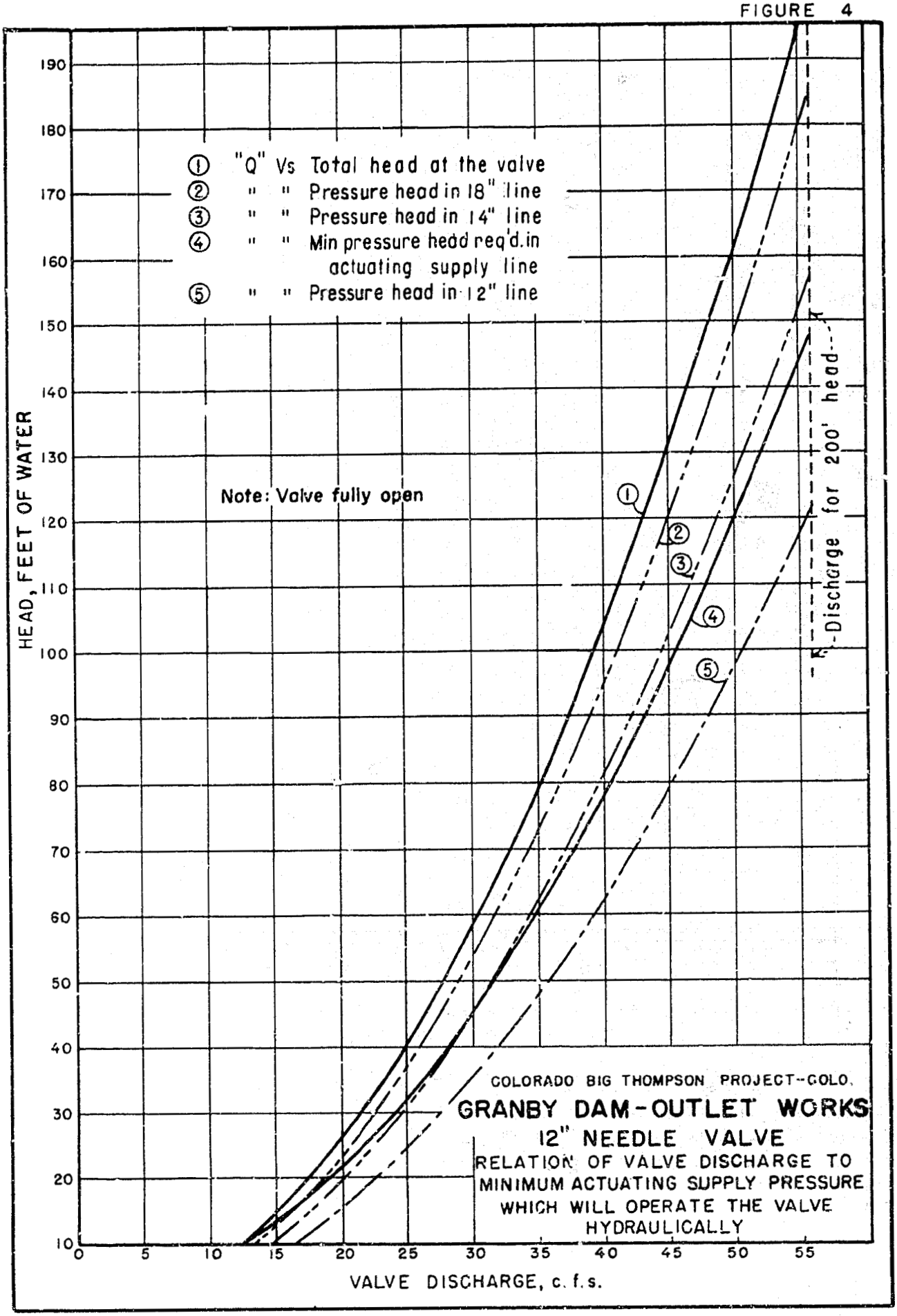
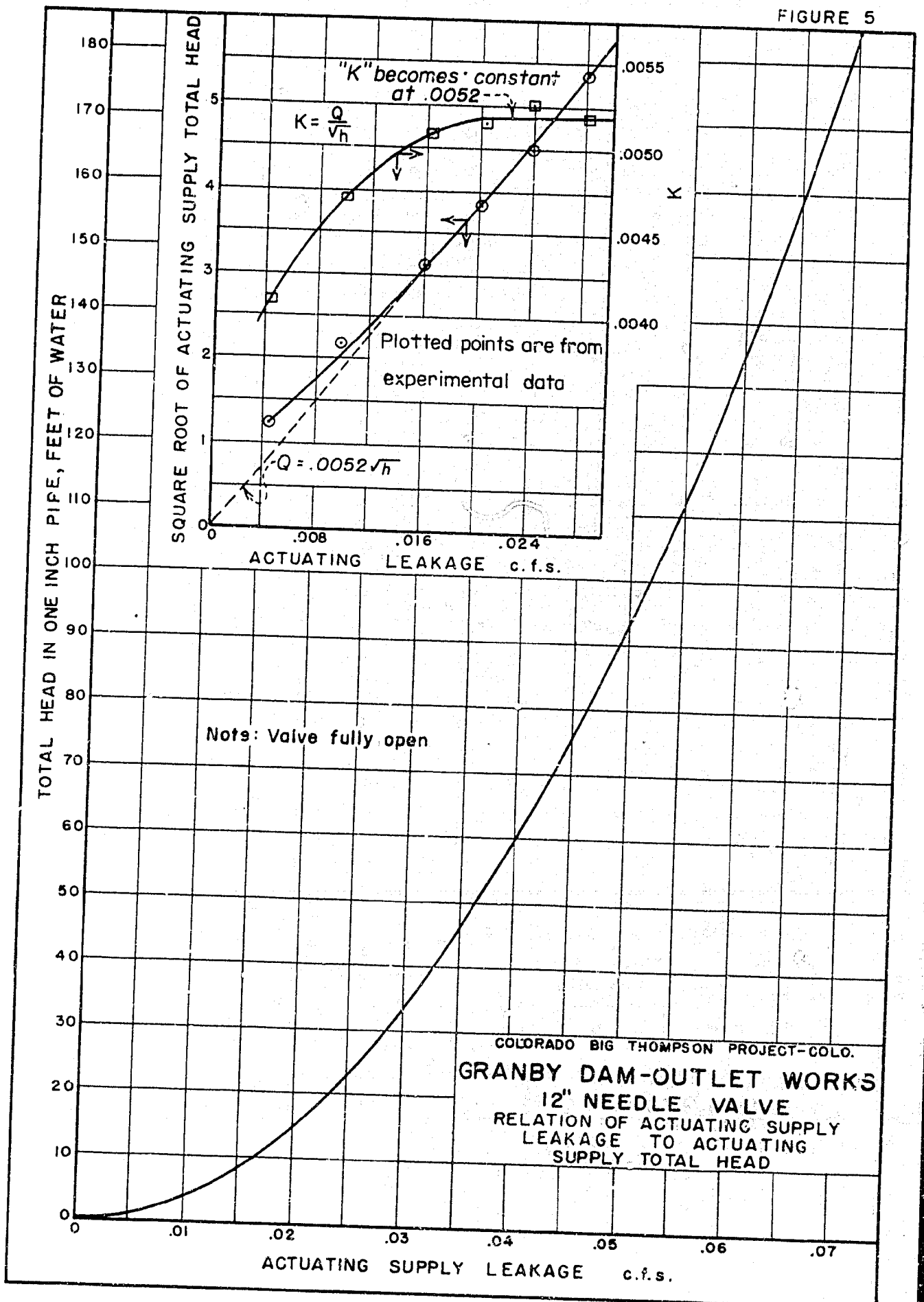
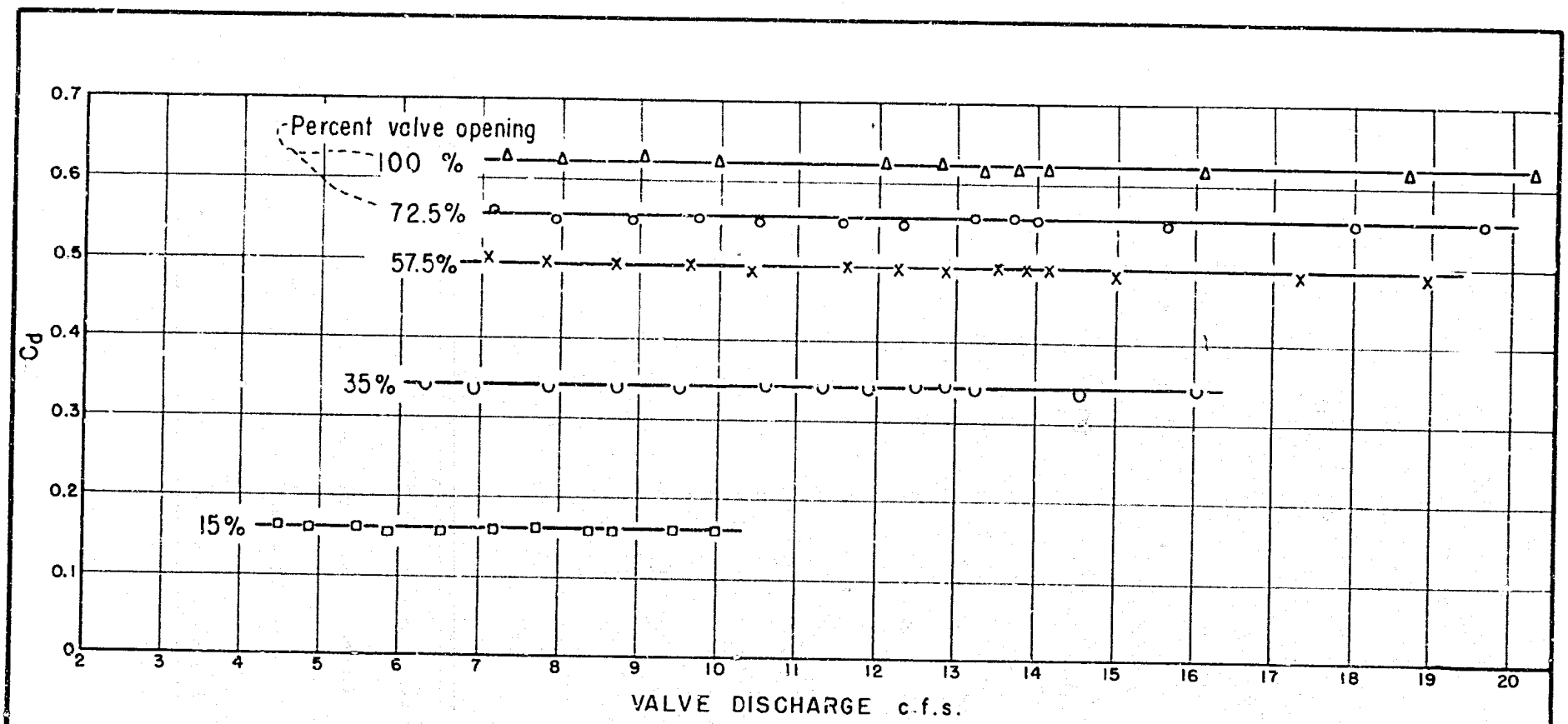

① "Q" Vs Total head at the valve
② " " Pressure head in 18" line
③ " " Pressure head in 14" line
④ " " Min pressure head req'd. in actuating supply line
⑤ " " Pressure head in 12" line
Note: Valve fully open
R-Discharge for 200' head
HEAD, FEET OF WATER
VALVE DISCHARGE, c.f.s.
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
0
5
10
15
20
25
30
35
40
45
50
55
COLORADO BIG THOMPSON PROJECT--COLO.
GRANBY DAM-OUTLET WORKS
12" NEEDLE VALVE
RELATION OF VALVE DISCHARGE TO MINIMUM ACTUATING SUPPLY PRESSURE WHICH WILL OPERATE THE VALVE HYDRAULICALLY

FIGURE 5


TOTAL HEAD IN ONE INCH PIPE, FEET OF WATER
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
.01
.02
.03
.04
.05
.06
.07
ACTUATING SUPPLY LEAKAGE c.f.s.
Note: Valve fully open
SQUARE ROOT OF ACTUATING SUPPLY TOTAL HEAD
5
4
3
2
1
0
"K" becomes constant at .0052---
K = Q/√h
Plotted points are from experimental data
Q = .0052√h
0
.008
.016
.024
ACTUATING LEAKAGE c.f.s.
K
.0055
.0050
.0045
.0040
COLORADO BIG THOMPSON PROJECT-COLO.
GRANBY DAM-OUTLET WORKS
12" NEEDLE VALVE
RELATION OF ACTUATING SUPPLY LEAKAGE TO ACTUATING SUPPLY TOTAL HEAD



Q = Valve discharge, c.f.s.
A = Area of 12-inch pipe.
h = Total head in 12-inch pipe.

$$C_d = \frac{Q}{A\sqrt{2gh}}$$

COLORADO BIG THOMPSON PROJECT-COLO.

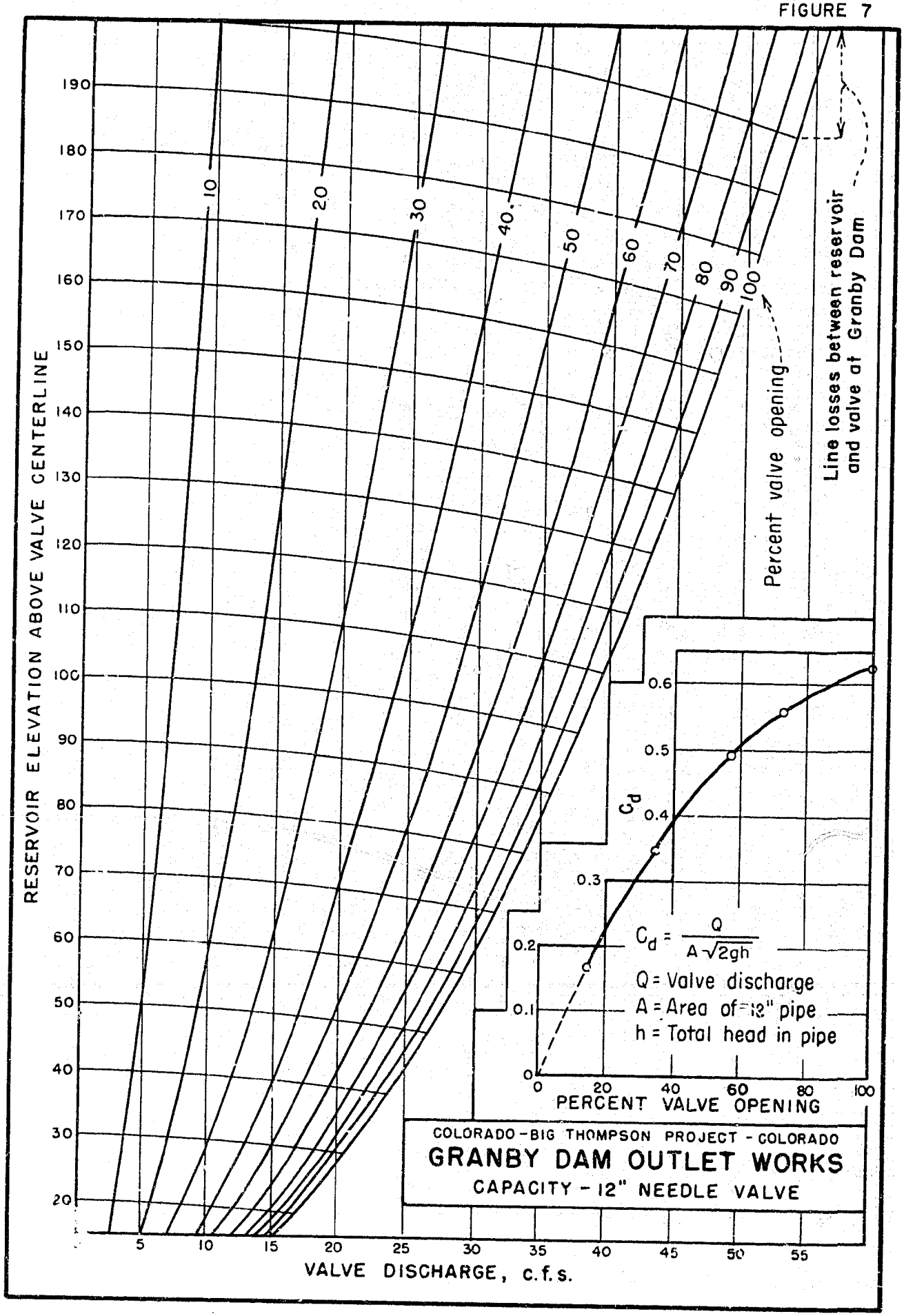
GRANBY DAM-OUTLET WORKS

12" NEEDLE VALVE

RELATION OF VALVE DISCHARGE TO COEFFICIENT OF DISCHARGE

FIGURE 6

FIGURE 7


RESERVOIR ELEVATION ABOVE VALVE CENTERLINE
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
20
30
40
50
60
70
80
90
100
Percent valve opening
Line losses between reservoir and valve at Granby Dam
5
10
15
20
25
30
35
40
45
50
55
VALVE DISCHARGE, c.f.s.
C_d
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
PERCENT VALVE OPENING
$C_d = \frac{Q}{A\sqrt{2gh}}$
Q = Valve discharge
A = Area of 12" pipe
h = Total head in pipe
COLORADO-BIG THOMPSON PROJECT - COLORADO
GRANBY DAM OUTLET WORKS
CAPACITY - 12" NEEDLE VALVE